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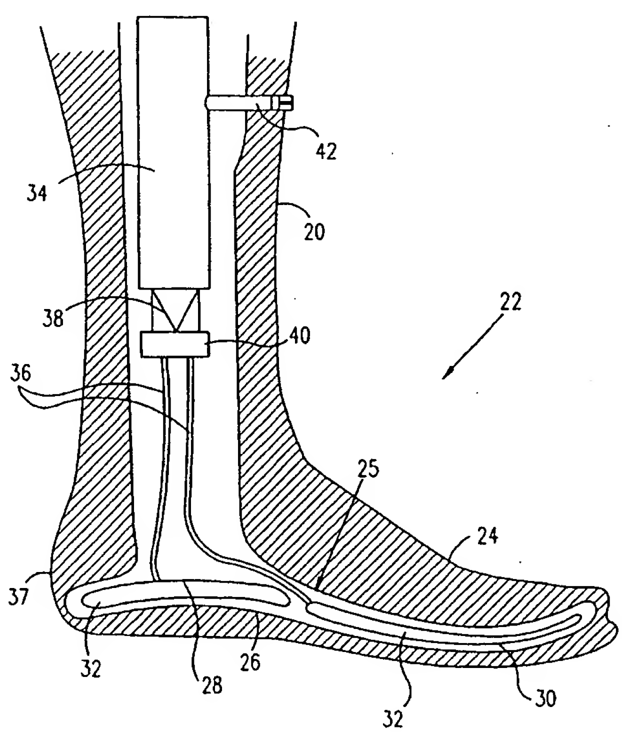
(54) Title: WALK INDUCED ENERGY ACCUMULATOR

(57) Abstract

Apparatus and methods for utilizing energy originating from walking. The apparatus includes a pump (22), which is actuated by walking movements to pump a fluid. The pump (22) may include at least one pillow (28, 30) containing the fluid. Preferably, the at least one pillow includes a pneumatic insole (25) formed of a rear upright arch (28) and a forward downward arch (30). The rear and front arches each contain a respective fluid pillow, such that during walking, the rear arch is flattened, and the front arch is bent, thereby driving fluid out of the respective pillows.



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WALK INDUCED ENERGY ACCUMULATOR

RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Patent Application 60/055,089, which is incorporated herein by reference.

FIELD OF THE INVENTION

The present invention relates generally to prostheses, and particularly to dynamic lower and upper limb prostheses.

BACKGROUND OF THE INVENTION

Leg prostheses are well known in the art. Generally, such prostheses are passive and have limited flexibility. In recent prosthesis models, the prosthesis has active functions, for example, a knee joint with swing motion which is mechanically and/or electronically controlled. These active functions are generally powered by batteries which must be recharged externally, limiting the range of use of the prosthesis. Also charging the battery is costly and may be inconvenient.

SUMMARY OF THE INVENTION

It is an object of some aspects of the present invention to provide improved apparatus and methods to provide power for active functions of a prosthesis.

In one aspect of the present invention, the power is provided by the mechanical energy of walking.

It is another object of some aspects of the present invention to provide a leg prosthesis having an internal energy accumulation mechanism.

It is yet another object of some aspects of the present invention to provide apparatus for utilizing and/or storing mechanical energy from walking.

It is a further object of some aspects of the present invention to provide apparatus and method for shock absorption in a leg prosthesis.

In some preferred embodiments of the present invention, user-actuated movements of a prosthesis are used to produce energy used for active operations of the prosthesis. Preferably, the energy is stored in an accumulator or battery so that the energy may be utilized independent of the movement of the prosthesis.

In some preferred embodiments of the present invention, the prosthesis provides motion damping and shock absorption, and energy received from the damping may be stored and utilized to power active operations of the prosthesis.

In preferred embodiments of the present invention, a leg prosthesis comprises a foot including a flexible insole, containing a fluid, in the sole thereof. When the flexible insole is compressed during normal walking, the fluid is driven into an accumulator vessel or a fluid pressure battery, through a one-way or otherwise controlled valve. The fluid in the accumulator or battery is used to supply energy for active functions of the prosthesis.

In some preferred embodiments of the present invention, the flexible insole comprises a plurality of layers of a flexible material, such as rubber and/or polyurethane, defining at least one pillow chamber between the layers. The insole is preferably formed in a flattened 'S' shape with a rear upright arch portion and a forward downward arch portion. Preferably, one or more tubes provide fluid communication between the at least one chamber and the accumulator. Flow-controlled valves are situated along the tubes and/or at the entrance of the accumulator, preventing the contents of the accumulator from returning back to the insole.

In some preferred embodiments of the present invention, the flexible insole comprises a resilient keel, preferably made up of two or more resilient portions, which encompass the at

least one fluid chamber. The portions are sequentially flexed and compressed during different stages of a normal walking gait, thus increasing the efficiency of energy utilization and allowing flexibility in directing the flow of the fluid. Preferably, some of the portions are flattened and squeezed when pressed on, while others are bent and squeezed. Thus, the flattening or bending provided by the motion of the foot cooperate with the pressure exerted on the foot during walking to drive the fluid with greater efficiency. In a preferred embodiment of the present invention, the flexible insole comprises two portions: a rear portion, which flattens at a first stage of the gait, and a front portion, which is bent during a second stage of the gait.

In a preferred embodiment of the present invention, multiple accumulators or fluid batteries are used to store walking energy. The fluid from the insole is directed to one of the batteries or accumulators that is not yet full. Alternatively, the fluid is directed according to a predetermined or programmable logic cycle.

Preferably, the fluid comprises air, although other fluids may be used, such as water or a suitable oil.

The energy stored in the accumulator or fluid batteries may be employed for various purposes including operating an active prosthesis and providing a bounce quality to gait of the prosthesis user as described for example in PCT publication PCT/IL96/00098, which is assigned to the assignee of the present invention and whose disclosure is incorporated herein by reference.

There is therefore provided in accordance with preferred embodiments of the present invention, a method of using mechanical energy, including converting mechanical energy generated by walking movements to an energy form usable for performing a desired task.

Preferably, converting the energy includes storing the energy.

Alternatively or additionally, converting the energy includes using the energy to move a joint and/or to provide power to a prosthetic limb.

Further alternatively, converting the energy includes using the energy to support a disabled limb.

Preferably, converting the energy includes converting energy generated when a foot strikes a surface.

Further preferably, converting the energy includes converting energy generated when a prosthetic foot engages a surface.

Alternatively or additionally, converting the energy includes converting energy

generated when a joint moves.

Preferably, converting the energy includes generating electrical energy.

Alternatively or additionally, converting the energy includes converting the energy to a form carried by a fluid.

Preferably, converting the energy includes applying the energy to a pillow containing a fluid.

Further preferably, applying the energy includes pressing on the pillow to extract the fluid therefrom.

Preferably, pressing on the pillow includes flattening the pillow.

Preferably, converting the energy includes driving the fluid into an accumulator.

Preferably, driving the fluid includes compressing the fluid in the accumulator.

Preferably, driving the fluid into the accumulator includes driving air into the accumulator.

Alternatively, driving the fluid into the accumulator includes driving an oil into the accumulator.

There is further provided in accordance with preferred embodiments of the present invention, apparatus for utilizing energy originating from walking including a pump, which is actuated by walking movements to pump a fluid.

Preferably, the pump includes at least one pillow containing the fluid.

Preferably, the at least one pillow includes a pneumatic insole.

Preferably, the pneumatic insole includes a rear upright arch and a forward downward arch.

Preferably, the rear and front arches each contain a respective fluid pillow, such that during walking, the rear arch is flattened, and the front arch is bent, thereby driving fluid out of the respective pillows.

Preferably, the apparatus includes a resilient keel which encapsulates the insole and exerts pressure thereon responsive to walking.

Preferably, the apparatus includes an accumulator for storing the fluid pumped by the pump.

Preferably, the accumulator includes a pressurized-fluid container.

Preferably, the fluid comprises air or oil.

Preferably, the pump includes a closed-circuit fluid system.

Alternatively, the pump includes an open-circuit fluid system.

Preferably, the apparatus comprises a shoe, containing the pump.

Alternatively, the apparatus comprises a prosthesis, which contains the pump.

Further alternatively, the apparatus comprises a walker, which contains the pump.

Preferably, the pump operates responsive to torsional motion of walking.

Alternatively or additionally, the pump operates responsive to the weight of a user of the apparatus, exerted against a surface on which the user is walking.

Preferably, the accumulator is mounted on a wearer's leg.

Preferably, the energy is utilized to turn a hinge.

There is also provided in accordance with a preferred embodiment of the present invention, a prosthesis, including an artificial limb and a mechanism coupled to the limb, which converts energy due to motion of the limb to an energy form usable for performing a desired task.

Preferably, the artificial limb includes an artificial leg.

Preferably, the artificial limb includes a pylon and the mechanism is situated within the pylon.

Further preferably, an accumulator is embedded within the pylon.

Preferably, the accumulator is for storing the energy.

Preferably, the prosthesis includes a joint, and the desired task includes moving the joint. Most preferably, the prosthesis includes a plurality of joints, which are moved using the energy. Alternatively or additionally, the joint couples a base portion to a leg portion of the prosthesis, and wherein the base portion is flexed at the joint in two or more different directions.

Preferably, the mechanism includes a pump which drives a fluid which carries the energy, wherein the fluid preferably includes air.

Preferably, the fluid is directed according to a logic cycle to perform the desired task. Most preferably, the prosthesis includes a controller which is programmed in accordance with the logic cycle to direct the fluid. Preferably, the controller includes an electronic processor or alternatively, a fluid logic processor.

In a preferred embodiment, the prosthesis includes one or more sensors, which provide signals to the controller responsive to motion of the prosthesis. Preferably, the sensors include pressure sensors. Alternatively or additionally the sensors receive electrophysiological signals

from a limb to which the prosthesis is fixed.

The present invention will be more fully understood from the following detailed description of the preferred embodiments thereof, taken together with the drawings, in which:

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic, sectional view of a prosthesis with a pump, in accordance with a preferred embodiment of the present invention;

Fig. 2 is a schematic, sectional view of a prosthesis utilizing energy produced by a pump, in accordance with a preferred embodiment of the present invention;

Fig. 3A is a schematic illustration showing details of the construction of the prosthesis of Fig. 2, in accordance with a preferred embodiment of the present invention;

Fig. 3B is a schematic illustration showing details of the construction of the prosthesis of Fig. 2, in accordance with another preferred embodiment of the present invention;

Figs. 4A and 4B are schematic illustrations showing details of a hinge used in the prosthesis of Fig. 2, in rest and deformed states, respectively, in accordance with a preferred embodiment of the present invention;

Fig. 5A is a graph showing forces exerted on the prosthesis of Fig. 2 during walking;

Figs. 5B-5E are schematic illustrations showing movement of the prosthesis of Fig. 2 at different stages in a walking gait, in accordance with a preferred embodiment of the present invention;

Fig. 6 is a schematic, cross-sectional view of a prosthesis, in accordance with a preferred embodiment of the present invention;

Fig. 7 is a schematic, cross-sectional view of a prosthesis, in accordance with another preferred embodiment of the present invention;

Fig. 8A is a schematic, pictorial illustration showing elements of a power system for a prosthesis, in accordance with a preferred embodiment of the present invention;

Fig. 8B is a schematic, cross-sectional illustration of the power system of Fig. 8A, in accordance with a preferred embodiment of the present invention;

Fig. 9 is a schematic, partly sectional illustration of a powered boot, in accordance with a preferred embodiment of the present invention; and

Fig. 10 is a schematic illustration showing a prosthesis fitted to the stump of a leg, in accordance with a preferred embodiment of the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Fig. 1 is a schematic sectional view of a leg prosthesis 20, including a dynamic power charging pump 22, in accordance with a preferred embodiment of the present invention. Prosthesis 20 is preferably shaped as a normal human leg, including a foot 24 comprising a strong and flexible material, such as rubber or a suitable plastic, such as polyurethane. A resilient insole 25, having a flattened 'S' shape, is situated within a keel 26. Keel 26 preferably runs along a substantial portion of the length of foot 24 and has leaf spring qualities, providing flexibility and resilience to prosthesis 20.

Insole 25 includes a rear pillow 28 and a forward pillow 30, each comprising at least one air chamber 32. Preferably, rear pillow 28 is shaped as an upright arch, while forward pillow 30 is shaped as a downward arch, as shown in the figure.

Preferably, pillows 28 and 30 comprise a rubber or similar material, which under pressure compresses the air within the pillow into an accumulator vessel 34 by way of tubes 36. The arch shape of pillows 28 and 30 aids in the air compression, and is fitted to the standard walking gait of prosthesis users. Particularly, pillow 28 is preferably flattened when heel 37 strikes the ground, and pillow 30 is curved and squeezed as the foot rolls onto the forefoot.

It is noted that instead of the two pillows 28 and 30, only one pillow may be used, or alternatively more than two pillows. Also, air pillows 28 and 30 may have any other suitable shape which enhances the flattening and/or squeezing functions of pump 22.

Chambers 32 may include drains and valves (not shown) for draining and connecting the chambers to tubes 36. Tubes 36 are connected to chambers 32 at any suitable position which allows suitable compression of air into tubes 36.

A controlled valve 38, preferably a one-way valve situated at the entrance to vessel 34, prevents air from escaping from the vessel. A fluid switching junction 40 is preferably situated at the entrance of vessel 34, controlling the flow into, and, optionally, out of, the vessel. Preferably, pillows 28 and 30 have one-way air inlet holes, as are known in the art, allowing air to enter chambers 32 when pressure is not applied to the pillows.

When prosthesis 20 engages a surface, pillows 28 and 30 are flattened and the air within chambers 32 is pushed through tubes 36 and junction 40 into vessel 34. It is noted that in a normal gait pattern, pressure is exerted first on rear pillow 28, when the heel 37 of foot 24 makes contact with the surface, and then on forward pillow 30, when the weight of the user shifts to the forefoot of foot 24.

Preferably, charging pump 22 may additionally be charged externally by suitable charging apparatus. Preferably, vessel 34 may be replaced or refilled externally, allowing energy supply additional to the energy received from pump 22. Preferably, an outlet 42 connecting to vessel 34 from the exterior of prosthesis 20 allows refilling the vessel from any suitable compressed air source without dismantling prosthesis 20. Alternatively or additionally, the external apparatus applies suction or any other force to operate pump 22 and thus recharge vessel 34.

The compressed air in vessel 34 may be used to perform active functions of prosthesis 20, and/or of another prosthesis worn by the user, such as an upper limb prosthesis. Such functions may include, for example, control of angle variation of the ankle, and pushing the foot backwards at the end of each stride (a "lift-off kick"), emulating the effect of a muscle.

In addition to utilizing gait energy, keel 26 gives prosthesis 20 a natural soft shoe quality with a deflectable "rolling" sole. Also, keel 26 preferably serves for shock absorption during the gait, as described hereinbelow.

Fig. 2 shows a prosthesis 48 for utilizing the energy produced by pump 22, contained therein, in accordance with a preferred embodiment of the present invention. Two artificial tendons 56 and 58 are each fixed at one end 60 thereof, while at their other ends they are connected to an ankle hinge element 50 of the prosthesis. Tendons 56 and 58 preferably comprise a flexible and durable fiber, such as Kevlar, which allows the tendons a measure of springiness. Alternatively, tendons 56 and 58 are wound around ankle hinge element 50 and connected to or constructed as part of keel 26. In order to change the angle of ankle element 50, tendons 56 and 58 are shortened or lengthened accordingly, using fluid power preferably provided by pump 22. For example, in order to bend hinge 50 forward, opening the ankle angle and pointing the toes, the upper portion of tendon 56, between end 60 and element 50 is shortened, and that of tendon 58 is lengthened.

Fig. 3A is a schematic illustration showing the connection between tendons 56 and 58 and keel 26, in accordance with a preferred embodiment of the present invention. Preferably, tendons 56 and 58 are fixed at one end 60 thereof to an anchor point 160, while at their other ends they are wound around ankle hinge element 50 and connected to keel 26 or constructed as part of keel 26.

Fig. 3B is a schematic illustration showing the connection between tendons 56 and 58 and keel 26, in accordance with another preferred embodiment of the present invention. In this

embodiment, tendons 56 and 58 are of a single, continuous construction with a connection element 59 which is securely embedded within a recess 305 in keel 26.

Referring back to Fig. 2, the effective length of tendons 56 and 58 is preferably controlled by hydraulic pillows 64 and 65, each of which bears against a respective one of the tendons. When pillow 64 is filled with a hydraulic fluid and at the same time fluid is extracted from pillow 65, the fluid pressure changes the shape of the pillows, causing the upper portion of tendon 58 to lengthen and that of tendon 56 to shorten, thereby exerting a moment about hinge element 50. Conversely, when the fluid is extracted from any of pillows 64 and 65, the respective tendons exert an opposite moment about the hinge element.

Hinge element 50 preferably has a total swing range of between 20° to 35°, most preferably 25°. Beyond the boundaries of the allowed movement of hinge element 50, movement is preferably prevented by the length of tendons 56 and 58. Preferably, the hinge may lock in substantially every position within its swing range. At any desired angle of hinge element 50, the flow into and out of pillows 64 and 65 may be prevented, thus substantially locking the element in its position. Due to the durability of the system of prosthesis 48, forces normally exerted on the prosthesis are not strong enough to overcome such locking.

Figs. 4A and 4B are schematic illustrations of hinge element 50 in a rest state and a deformed state, respectively, in accordance with a preferred embodiment of the present invention. Preferably, hinge element 50 comprises a resilient material, such as an elastomer, which deflects and slightly deforms in a substantially vertical direction under load. Element 50 is preferably hollow, adding flexibility to the element. Preferably, when element 50 in a rest state 150, it is substantially round with two upper teeth 152 and a lower tooth 153 symmetrically situated around an axis x1. When element 50 is brought under downward pressure, it deforms to a oval state 151, which is also substantially symmetrical around axis x1. However, when a side force is applied on element 50, for example when the front part of foot 24 is lifted, element 50 deforms as shown in Fig. 3B. Tooth 153 moves to one side of axis x1, and the width of element 150 varies between a1 and a2. Thus, element 50 acts as a restoring spring and recoils due to the rotation moment which caused the movement to the new position.

The amount of fluid within pillows 64 and 65 is preferably controlled by conversion tanks 52, preferably one such tank for each pillow. Preferably, the hydraulic fluid comprises a non-compressible liquid, such as a suitable oil, although other fluids may also be used. Each conversion tank 52 comprises two chambers, a lower chamber 68, preferably filled with air, and

an upper chamber 70, preferably filled with hydraulic fluid. Chambers 68 and 70 are separated by a flexible diaphragm 66, which preferably comprises a suitable flexible material such as rubber or polyurethane. Diaphragm 66 flexes and moves under pressure variations of the air (or other fluid) in chamber 68, thus causing fluid to flow between pillow 64 and 65 and chambers 70 through a junction 44.

A controller 72 preferably controls junctions 40 and 44, so that pressurized fluid enters and leaves chambers 68 according to a predetermined algorithm, for example, an algorithm that causes element 50 to flex and rotate naturally in response to the user's gait. Junction 40 controls the flow between pump 22 and conversion tanks 52, as well as optionally into and out of an accumulator vessel such as vessel 34, shown in Fig. 1. Controller 72 preferably comprises an electronic, battery-powered processor, as is known in the art, which is programmed to open and close the appropriate valves. Alternatively, controller 72 operates based on fluid logic technology, as is also known in the art, to achieve low energy operation.

Preferably, prosthesis 48 comprises one or more sensors 82, 84, 86 and 88 which provide input to the processor of controller 72. The sensors preferably comprise strain gauges, pressure gauges or any other gauges which provide information on the movement of prosthesis 48. Preferably, the one or more sensors include sensors 82 on the bottom surface 90 of prosthesis 48 which report the areas in which the prosthesis forms contact with a surface beneath it and/or the pressure level of the contact. Further preferably, the sensors include sensors 86 on the stump 94 of the user and/or sensors 84 at the connection surface between stump 94 and prosthesis 48, which report the state of the contact between the prosthesis and the stump. Alternatively or additionally, the sensors include sensors 88 on hinge element 50, or other components of prosthesis 48 which report the state of the components. Such state may include the rotation angle, the speed of rotation, rotation acceleration and/or any other parameters of the components.

Preferably, the processor of controller 72 is programmed to actuate movements of hinge element 50 and/or other components of prosthesis 48 responsive to signals from sensors 80. The processor preferably includes simple software or logic circuits, which are generally sufficient when taken together with the ability of the human brain to adjust to the prosthesis. Preferably, the processor determines most likely next moves of the amputee according to the current state of prosthesis 48 and past states of the prosthesis and accordingly actuates hinge element 50. Preferably, the processor verifies thereafter whether the prediction of the most

likely move was correct and accordingly adjusts its predictions of the movements of the user of the prosthesis. Thus, the processor "learns" the actions of the user and within a training period adjusts itself to the user.

Alternatively or additionally, the user and/or a physician may change settings of the processor according to the performance during a rehabilitation training period. Likewise, changes may be made in the settings of the processor later on due to changes in the age and/or medical state of the user.

The algorithm of controller 72 preferably includes a stiffening of hinge element 50 when an impact is sensed. Alternatively or additionally, the algorithm includes causing the heel to touch the surface before the front of the keel touches the surface when the angle of hinge element 50 indicates the user is walking downhill. Similar adjustments are preferably taken when uphill walking, and stair ascending or descending are identified. Such algorithms enhance the safety of use of prosthesis 48.

Other algorithms used by controller 72 may be as in the Motion Measurement and Biomechanics Systems, available from Peak Performance Technologies, Inc, Englewood, Colorado, 80112 USA, and as described in http://www.peakperform.com/, which is incorporated herein by reference. Still further algorithms may be as in the Footmaxx computerized gait and pressure analysis system available from Footmaxx, Toronto, Ontario, Canada.

Preferably, prosthesis 48 has extended shock absorption properties which prevent the user from feeling forces exerted on the prosthesis. When the prosthesis touches a surface, the resilience of keel 26 and insole 25 absorbs a portion of the shock. Pillows 28 and 30 are then flattened gradually both providing energy and further absorbing the shock. The resilience and springiness of hinge element 50 further provides some shock absorption due to its deformation and retrieving springiness. Additional shock absorption is preferably provided the flexibility of tendons 56 and 58. Alternatively or additionally, hydraulic pillows 64 and 65 include within them one or more air capsules 98 which add additional resilience to prosthesis 48.

Fig. 5A is a schematic graph of the force exerted by prosthesis 48 on a surface during normal gait. Figs. 5B-5E are schematic illustrations of prosthesis 48 at different stages of the normal gait. Figs. 5A-5E illustrate one method of use of prosthesis 48, in accordance with a preferred embodiment of the present invention.

As shown in Fig. 5B, when the heel of prosthesis 48 contacts a surface, the leg part of

the prosthesis is at substantially 90° with respect to the foot of the prosthesis. In order to absorb the high degree of shock due to the contact with the surface, hinge 50 is forced by pillow 64 to deform and/or rotate clockwise to bring the front of the foot into contact with the surface, as shown in Fig. 5C. At this stage the angle between the leg and foot of the prosthesis is larger than 90°, preferably by about 10°. Thus, part of the shock is absorbed and the gait is stabilized. Thereafter, the prosthesis moves to a mid-stance orientation, shown in Fig. 5D, while hinge element 50 slowly recoils back to the 90° angle between the foot and leg. The recoiling of element 50 is associated with additional damping which is provided for softening the harsh surface reaction.

Thereafter, the prosthesis moves ahead to a weight shift orientation at which the force of the prosthesis against the surface is maximized. When the weight shift orientation is reached, the hinge is locked by preventing flow from or to the pillows. Thereafter, the flexible keel of the prosthesis curves at the forefoot, while hinge element 50 is still locked. When a liftoff orientation shown in Fig. 5E is reached, the controller causes the pillows to operate and provide a power kick to hinge element 50, empowering an energetic gait.

Preferably, as described above, prosthesis 48 includes one open fluid system, comprising pillows 32 and chambers 68, between which atmospheric air is transferred, and one closed system, comprising chambers 70 and pillows 64 and 65. It will be appreciated, however, that prostheses and other apparatus may be produced in accordance with the principles of the present invention so as to include greater or lesser numbers of fluid systems, which may be open or closed and may contain either compressible or incompressible fluids, depending on the requirements of the particular application. Also, greater or lesser numbers of pillows and tendons in various arrangements, or other forms of energy utilization may be incorporated, in accordance with alternative embodiments of the present invention. For example, a single pillow may be used to actuate two separate tendons simultaneously.

Fig. 6 is a cross-sectional schematic view of a prosthesis 100, in accordance with a preferred embodiment of the present invention. Prosthesis 100 includes a fluid system which includes a plurality of pairs of tendons 102 and pillows 104. The fluid system is preferably situated above the knee of the prosthesis where there is sufficient space to store the pillows while having substantially no affect on the moment of inertia of the prosthesis. An accumulator (not shown, but similar in principles of operation to that described hereinabove) is preferably situated below the knee. Preferably, tendons 102 and pillows 104 are organized in pairs 106,

each of which actuates a specific element. In an exemplary embodiment, there are five pairs of pillows 104 and tendons 102, which respectively control a knee joint, a fore-aft axis of an ankle joint, a sideways axis of the ankle joint, a mid-foot fore-aft axis, and a fore-foot fore-aft axis. Preferably, pillows 104 are of different sizes according to the force required to actuate their specific elements. Preferably, pulleys and/or other direction elements are used to properly direct the tendons to the element being actuated thereby.

Fig. 7 is a cross-sectional schematic view of a prosthesis 120, in accordance with another preferred embodiment of the present invention. Prosthesis 120 has a circular arrangement, in which a plurality of pillows 122, similar to pillows 64 and 65 of Fig. 2, are arranged around an inner circumference of prosthesis 120. A plurality of tendons 124, preferably, one for each pillow 122, are situated on the inner side of the pillows, toward the center of prosthesis 120. The center of prosthesis 120 is thus left empty for various other equipment, such as an accumulator 126, which serves the same function as accumulator 34 of Fig. 1. Preferably, a durable housing container 128 prevents pillows 122 from extending outwards when they are being filled. Container 128 preferably comprises light and strong composite materials which withstand the pressure of pillows 122.

Fig. 8A is a schematic pictorial illustration showing elements of a pillow-powered system 130, and Fig. 8B is a schematic, cross-sectional illustration of the system, in accordance with a preferred embodiment of the present invention. Preferably, system 130 comprises four tendons 132, 134, 136 and 138, which control all four rotations of keel 26 or another component of a prosthesis comprising system 130. Two of the tendons 132 and 136 are preferably connected at one end to each other and to keel 26. Preferably, at their connection, tendons 132 and 136 define a recess 139 which is shaped and sized to tightly receive a compatible connector 140. Connector 140 is connected to tendons 134 and 138 such that when connector 140 is inserted into recess 139, tendons 132, 134, 136 and 136 can manipulate keel 26 in all four directions. As shown in Fig. 8B, each tendon 132, 134, 136 and 138 is actuated by a respective pillow 142, 144, 146 and 148.

Alternatively or additionally, three pillows may be used as shown in Fig. 7, and one of the tendons, such as tendon 132 is anchored, preferably via springs 179, to a container holding system 180.

The ability to control the side angle of the keel afforded by system 130 allows additional control over the prosthesis, which is useful, for example, when walking along slanted surfaces.

In other preferred embodiments of the present invention, other sources of walking energy may be used to operate the pump. For example, the compression of flexible hinge 50, as described in PCT/IL96/00098, or the torsional movement of the ankle provided by the hinge may be used to operate the pump. Alternatively, in other preferred embodiments in which the prosthesis comprises a pylon, the pressure exerted on the pylon may be used to operate a pump, preferably built into the pylon. In this embodiment, the interior of the pylon may be used to store the compressed air therein.

In other preferred embodiments of the present invention, the pump described in conjunction with Fig. 1 is part of an exoskeleton device. In one such embodiment, the pump is preferably incorporated within a shoe, which may be used by individuals having either normal or disabled limbs. In particular, the exoskeleton device may be used by mountain climbers, skiers and other people who perform physically challenging tasks, as well as by individuals who have disabled limbs. The compressed air is preferably stored in air tanks wrapped around the individual's leg. Alternatively or additionally, the compressed air is used to operate a dynamo which converts the energy to another form, preferably electrical energy. The electrical energy is stored in suitable batteries and/or used to perform substantially any desired function.

Fig. 9 is a schematic illustration of an exoskeleton boot 200, in accordance with a preferred embodiment of the present invention. Boot 200 preferably comprises one or more pillows 202 and 204 which together with respective tendons 206 and 207 control the boot in a similar manner to that described above in conjunction with Fig. 2. Preferably, pillow 202 and its respective tendon 206 control the front 214 of boot 200, while pillow 204 and its respective tendon 207 control the back 216 of the boot. Preferably, boot 200 further comprises an insole 210 and an accumulator 212, which provide energy to pillows 202 and 204 in a manner similar to that of pump 22 described above.

In another such preferred embodiment of the present invention, the pump described in conjunction with Fig. 1 is incorporated within a walker which assists, supports and/or stabilizes walking of disabled people.

As noted above, although the above embodiments comprise open-circuit air pumps, other compressible and non-compressible fluids may be used in the pump. In such cases the pump preferably comprises a closed system which does not communicate with the atmosphere. A bleeder is preferably used to provide the fluid to the pump. It is also noted that more than one pump may be used within a single prosthesis.

Fig. 10 is a schematic illustration of a prosthesis 250, in accordance with a preferred embodiment of the present invention. Prosthesis 250 comprises at an extreme end a pad 252 which receives an amputated limb 256 of a user. Preferably, within pad 252 prosthesis 250 comprises a plurality of input devices 254 which may be controlled by the user. Preferably, input devices 254 comprise contact switches and/or sensors. Limb 256, preferably comprises transplanted neuro-switches which are attached to intact muscles and/or neurons of the user. In a preferred embodiment of the present invention, the muscles of the user may be modified and/or split to enhance the fitting between input devices 254 and the amputated limb 256 of the user. Thus, limb 256 preferably forms an integral interface, similar to a multi-pin connector, which is used by the user to control input devices 254.

Prosthesis 250 preferably further comprises a processor 258 which receives signals from input devices 254 and responsive to these signals controls prosthesis 250. Preferably, prosthesis 250 comprises a plurality of hinge elements 260 which are controlled using pump 22 and pillows 64 and 65 as described above in conjunction with Figs. 1 and 2. Alternatively or additionally, any other controlled elements may be incorporated within prosthesis 250.

During a training period, processor 258 is trained to understand commands from the user, which are passed through limb 256, while simultaneously the user gets used to passing commands through limb 256. Preferably, processor 258 comprises one or more neural networks or neural network simulation programs which are trained in accordance with the needs of the user. A software program for processor 258 is preferably prepared individually for each user according to the number, diversity and nature of the neural switches on limb 256 and according to the number of functions of prosthesis 250 which are to be controlled by the user.

Preferably, a Programmable Limb Simulator Trainer (PLST) is used to help train processor 258 and the user, and thus reduce the training time required by the user to adapt to prosthesis 250. The PLST preferably comprises an interface which connects to limb 256 and an output device which responds to commands given by the limb. The output device preferably comprises an output screen which shows an animated illustration of a prosthesis which moves according to the commands given by the limb. Preferably, the animated limb is shown together with an image of the user, such that the user may psychologically accommodate to his or her image with the prosthesis. Preferably, the user may change the effect of his commands according to a desired consequence of a command that he/she is successful in conveying through the limb. Alternatively or additionally, the output device comprises a three-dimensional

prosthesis model which the user practices keeping stable.

It will also be appreciated that while preferred embodiments are described hereinabove with reference to leg prosthesis, the principles of the present invention may also be applied to other prosthetic limbs.

It will be appreciated that the preferred embodiments described above are cited by way of example, and the full scope of the invention is limited only by the claims.

CLAIMS

1. A method of using mechanical energy, comprising converting mechanical energy generated by walking movements to an energy form usable for performing a desired task.

2. The method of claim 1, wherein converting the energy comprises storing the energy.

3. The method of claim 1 or claim 2, wherein converting the energy comprises using the energy to move a joint.

4. The method of claim 1 or claim 2 wherein converting the energy comprises using the energy to provide power to a prosthetic limb.

5. The method of claim 1 or claim 2, wherein converting the energy comprises using the energy to support a disabled limb.

6. The method of claim 1 or claim 2, wherein converting the energy comprises converting energy generated when a foot engages a surface.

7. The method of claim 6, wherein converting the energy comprises converting energy generated when a prosthetic foot strikes a surface.

8. The method of claim 1 or claim 2, wherein converting the energy comprises converting energy generated when a joint moves.

9. The method of claim 1 or claim 2, wherein converting the energy comprises generating electrical energy.

10. The method of claim 1 or claim 2, wherein converting the energy comprises converting the energy to a form carried by a fluid.

11. The method of claim 10, wherein converting the energy comprises applying the energy to a pillow containing a fluid.

12. The method of claim 11, wherein applying the energy comprises pressing on the pillow to extract the fluid therefrom.

13. The method of claim 12, wherein pressing on the pillow comprises flattening the pillow.

14. The method of claim 10, wherein converting the energy comprises driving the fluid into an accumulator.

15. The method of claim 14, wherein driving the fluid comprises compressing the fluid in the accumulator.

16. The method of claim 14 or claim 15, wherein driving the fluid into the accumulator comprises driving air into the accumulator.

17. The method of claim 14, wherein driving the fluid into the accumulator comprises driving an oil into the accumulator.

18. Apparatus for utilizing energy originating from walking comprising a pump, which is actuated by walking movements to pump a fluid.

19. Apparatus as in claim 18, wherein the pump comprises at least one pillow containing the fluid.

20. Apparatus as in claim 19, wherein the at least one pillow comprises a pneumatic insole.

21. Apparatus as in claim 20, wherein the pneumatic insole comprises a rear upright arch and a forward downward arch.

22. Apparatus as in claim 21, wherein the rear and front arches each contain a respective fluid pillow, such that during walking, the rear arch is flattened, and the front arch is bent, thereby driving fluid out of the respective pillows.

23. Apparatus as in claim 20, and comprising a resilient keel which encapsulates the insole and exerts pressure thereon responsive to walking.

24. Apparatus as in claim 19, and comprising an accumulator for storing the fluid pumped by the pump.

25. Apparatus as in claim 24, wherein the accumulator comprises a pressurized-fluid container.

26. Apparatus as in claim 19, wherein the fluid comprises air.

27. Apparatus as in claim 19, wherein the fluid comprises oil.

28. Apparatus as in claim 19, wherein the pump comprises a closed-circuit fluid system.

29. Apparatus as in claim 18, wherein the pump comprises an open-circuit fluid system.

30. Apparatus as in any of claims 18-29, wherein the apparatus comprises a shoe, containing the pump.

31. Apparatus as in any of claims 18-29, wherein the apparatus comprises a prosthesis, which contains the pump.

32. Apparatus as in any of claims 18-29, wherein the apparatus comprises a walker, which contains the pump.

33. Apparatus as in any of claims 18-29, wherein the pump operates responsive to torsional motion of walking.

34. Apparatus as in any of claims 18-29, wherein the pump operates responsive to the weight of a user of the apparatus, exerted against a surface on which the user is walking.

35. Apparatus as in claim 24, wherein the accumulator is mounted on a wearer's leg.

36. Apparatus as in any of claims 18-29, wherein the energy is utilized to turn a hinge.

37. A prosthesis, comprising:

an artificial limb; and

a mechanism coupled to the limb, which converts energy due to motion of the limb to an energy form usable for performing a desired task.

38. The prosthesis of claim 37, wherein the artificial limb comprises an artificial leg.

39. A prosthesis as in claim 37 or claim 38, artificial limb comprises a pylon and wherein the mechanism is situated within the pylon.

40. The prosthesis of claim 39, and comprising an accumulator embedded within the pylon.

41. The prosthesis of claim 37, and comprising an accumulator for storing the energy.

42. The prosthesis of claim 37, wherein the prosthesis comprises a joint, and wherein the desired task comprises moving the joint.

43. The prosthesis of claim 42, wherein the prosthesis comprises a plurality of joints, which are moved using the energy.

44. The prosthesis of claim 42 or 43, wherein the joint couples a base portion to a leg portion of the prosthesis, and wherein the base portion is flexed at the joint in two or more different directions.

45. The prosthesis of claim 37, wherein the mechanism comprises a pump which drives a fluid which carries the energy.

46. The prosthesis of claim 45, wherein the fluid comprises air.

47. The prosthesis of claim 45, wherein the fluid is directed according to a logic cycle to perform the desired task.

48. The prosthesis of claim 47, and comprising a controller which is programmed in accordance with the logic cycle to direct the fluid.

49. The prosthesis of claim 48, wherein the controller comprises an electronic processor.

50. The prosthesis of claim 48, wherein the controller comprises a fluid logic processor.

51. The prosthesis of any of claims 48-50, and comprising one or more sensors, which provide signals to the controller responsive to motion of the prosthesis.

52. The prosthesis of claim 51, wherein the sensors comprise pressure sensors.

53. The prosthesis of claim 51, wherein the sensors receive electrophysiological signals from a limb to which the prosthesis is fixed.

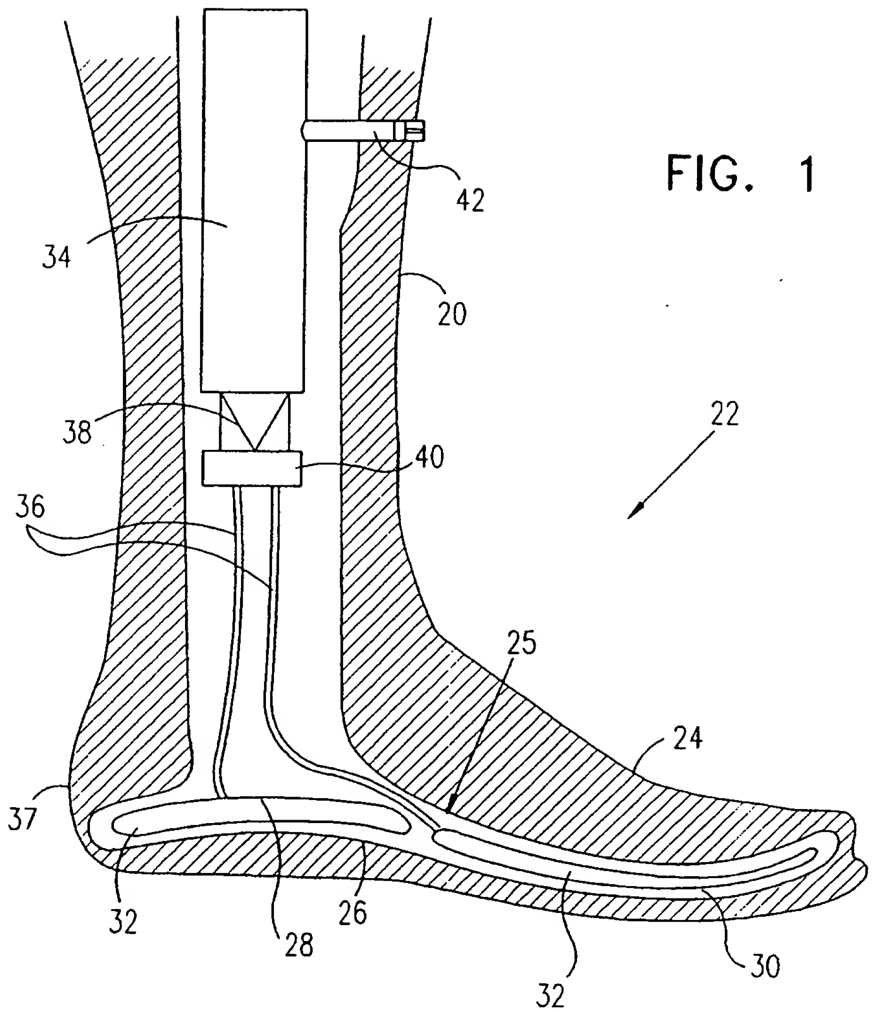

FIG. 1

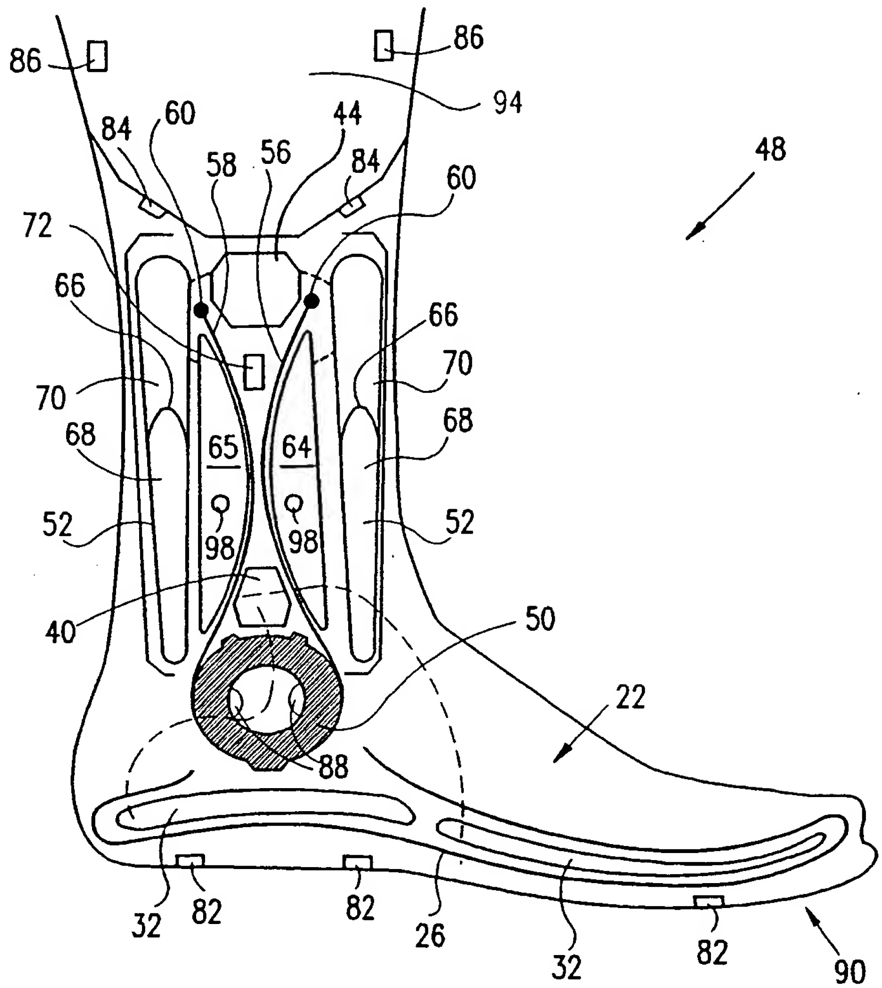
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FIG. 2

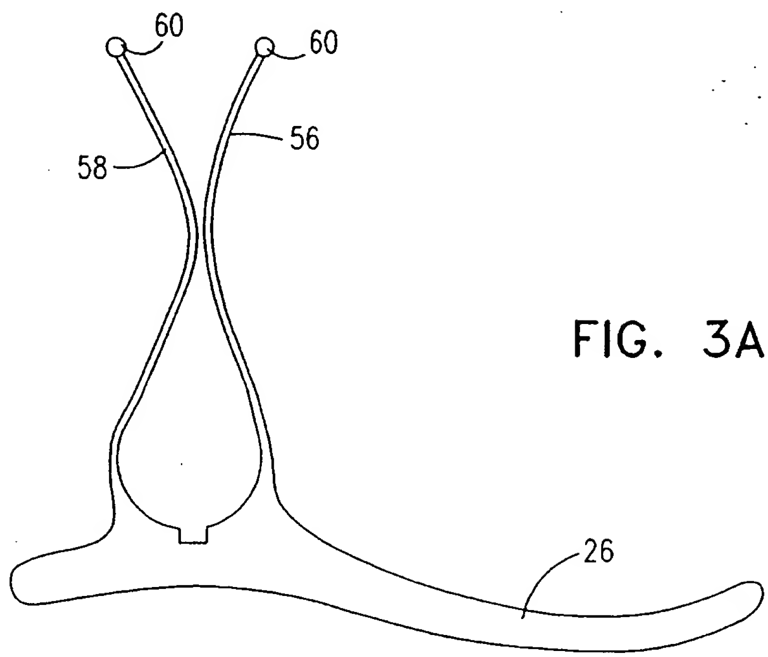


FIG. 3A

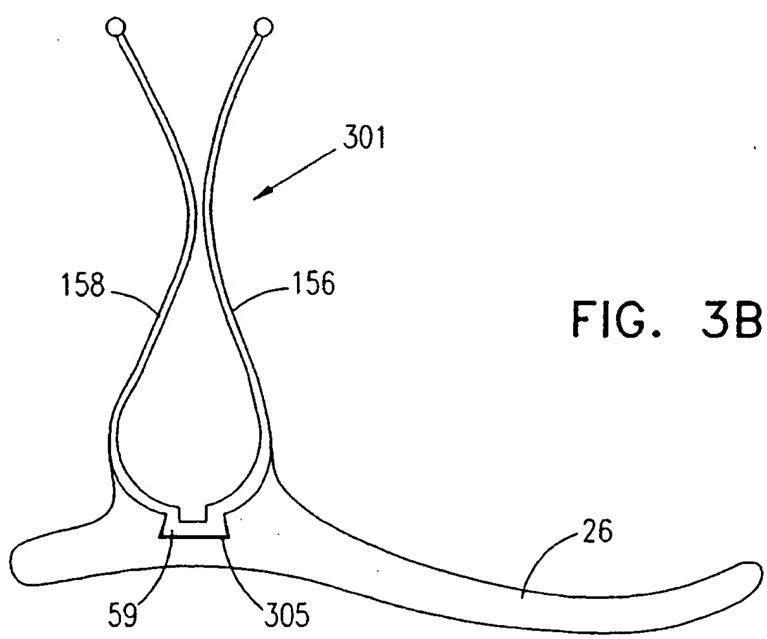


FIG. 3B

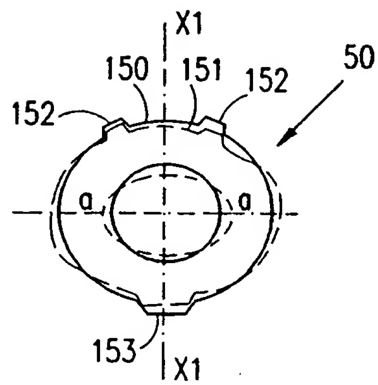


FIG. 4A

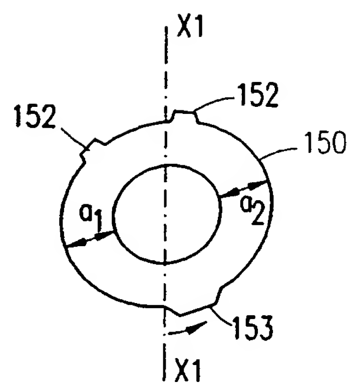
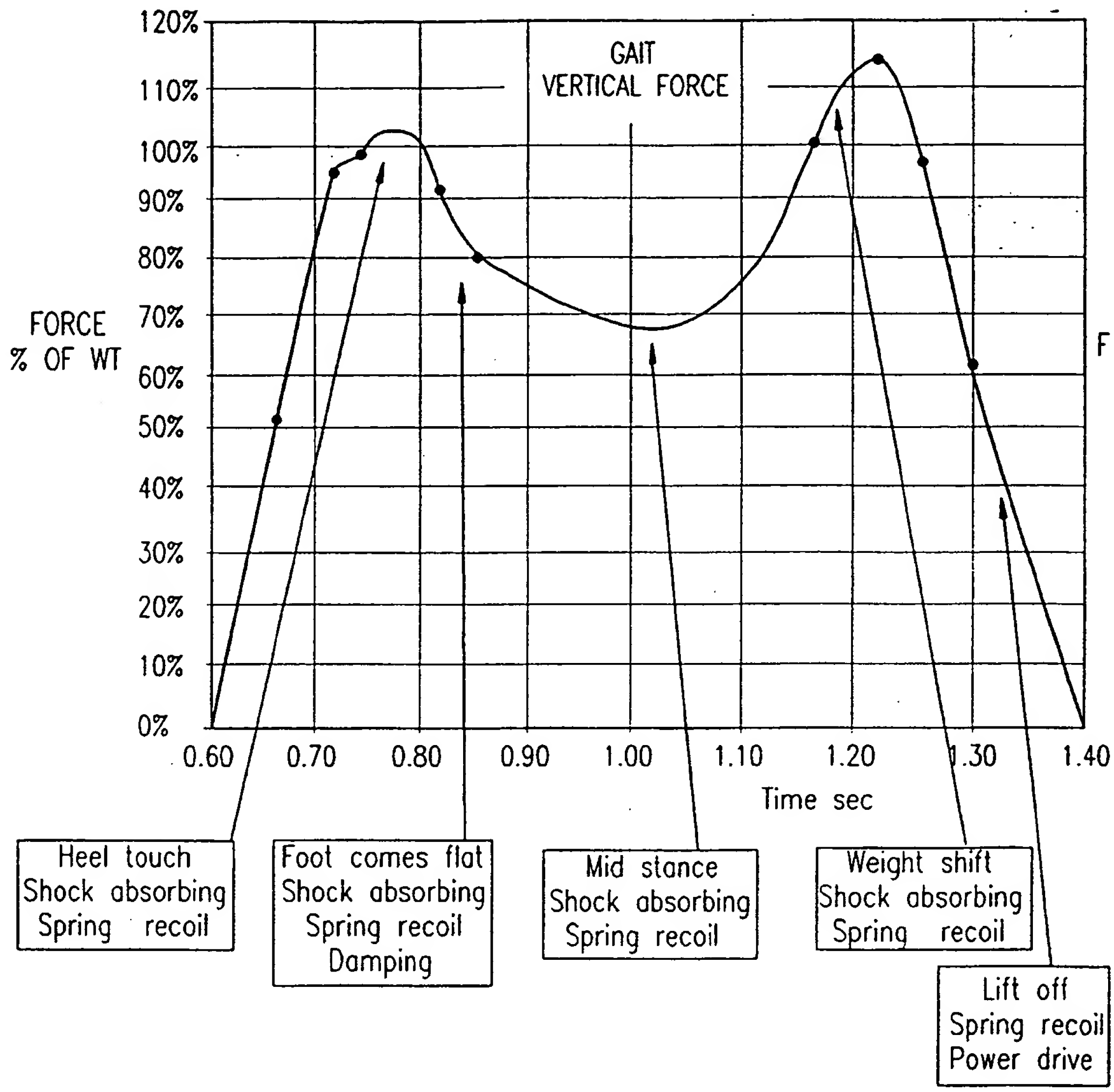


FIG. 4B

FIG. 5A



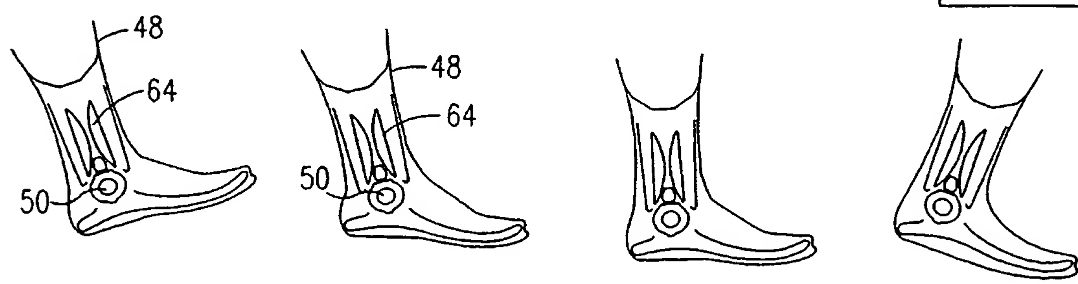


FIG. 5B FIG. 5C FIG. 5D FIG. 5E

FIG. 6

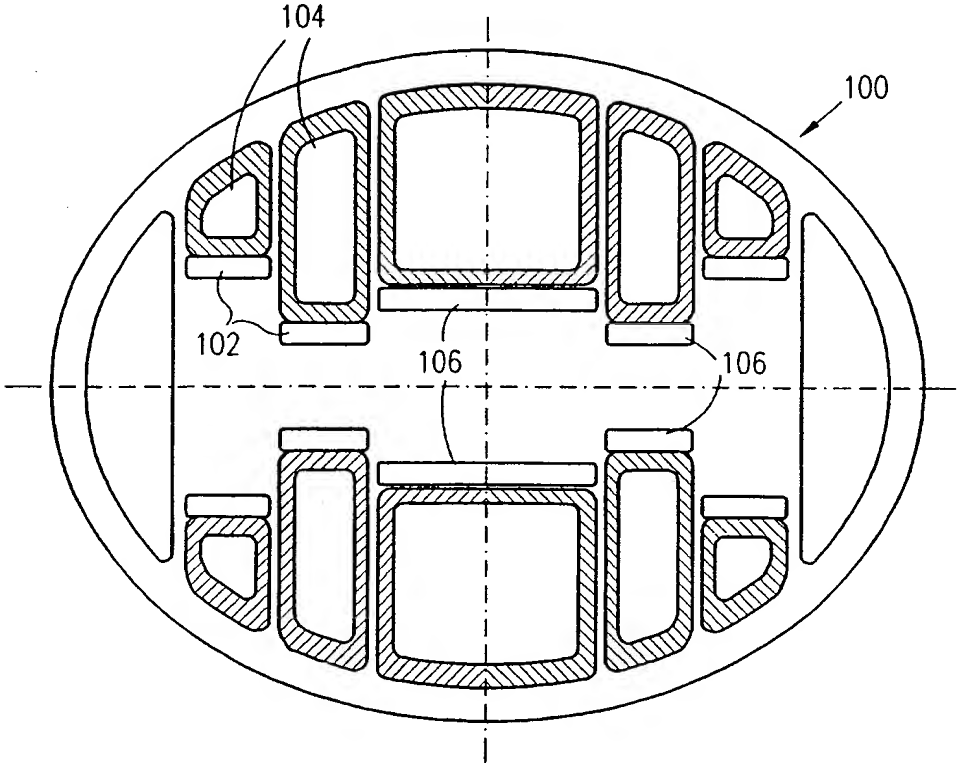


FIG. 7

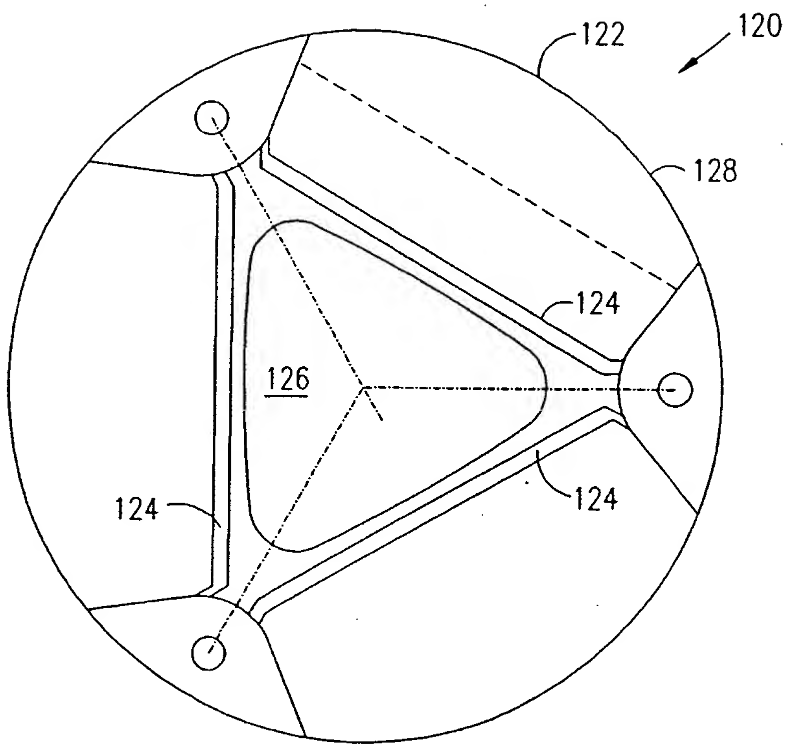


FIG. 8A

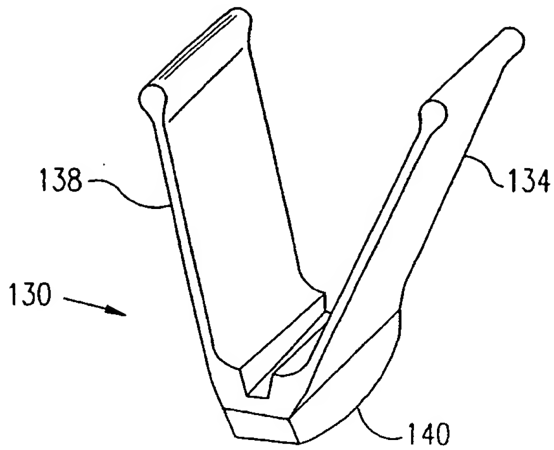


FIG. 8B

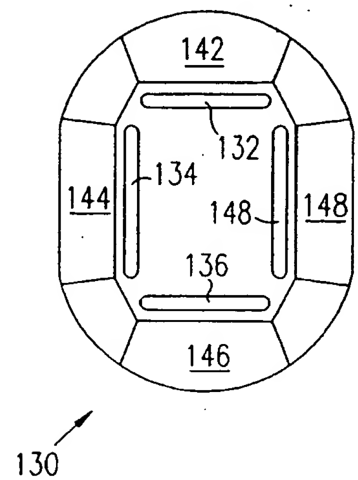
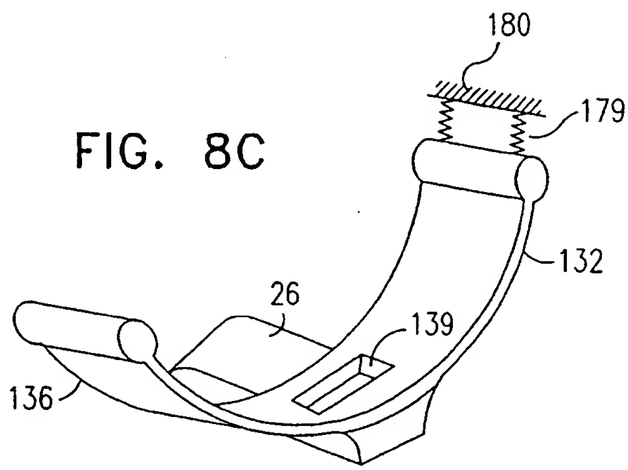


FIG. 8C



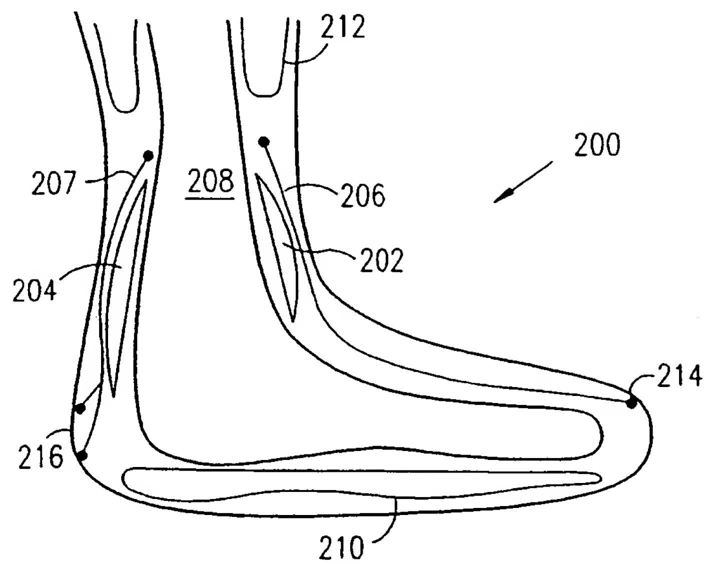


FIG. 9

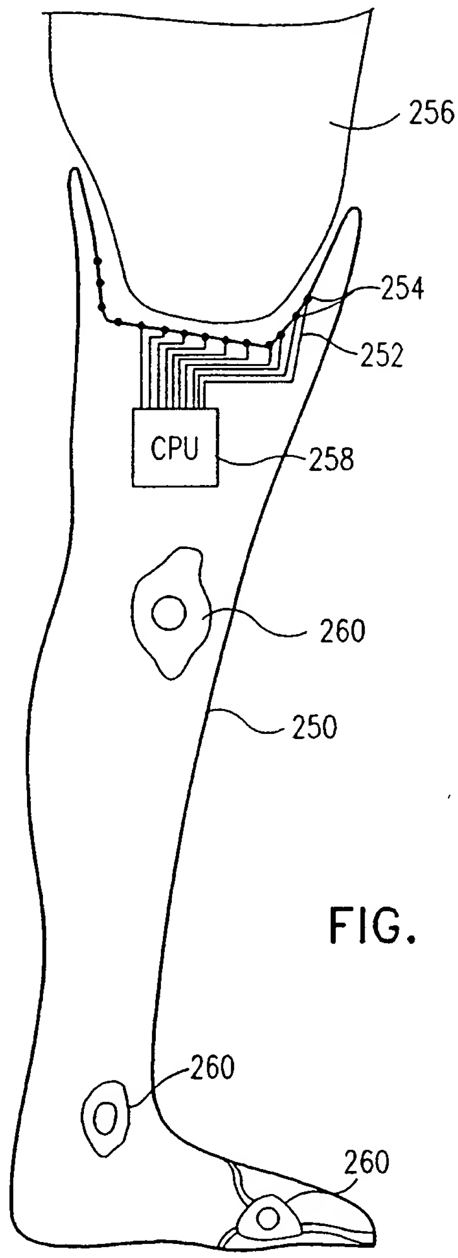


FIG. 10